Airborne Dispersal of Bacteria in Tomato and Pepper Transplant Fields

T. B. McINNES, Graduate Research Assistant, and R. D. GITAITIS, Associate Professor, Department of Plant Pathology, Coastal Plain Experiment Station, University of Georgia, Tifton 31793; S. M. McCARTER, Professor, Department of Plant Pathology, University of Georgia, Athens 30602; C. A. JAWORSKI, Soil Scientist, USDA-ARS, Tifton, GA 31793; and S. C. PHATAK, Professor, Department of Horticulture, Coastal Plain Experiment Station, University of Georgia, Tifton 31793.

ABSTRACT

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Aerosols were sampled over commercial fields and experimental plots of tomato transplants in southern Georgia. Viable bacteria were detected during three sample periods, (0700–0900, 1130–1330, and 1530–1730 hours). The highest concentrations of bacteria were collected from 1530 to 1730 hours. Significantly fewer bacteria were collected after periods of rain or irrigation. In contrast, the practice of clipping plants to achieve plant uniformity increased the number of bacteria collected. However, this effect decreased with subsequent clipping (as transplant harvest approached). The number of bacteria collected also was higher when transplants were harvested. An increase in the number of airborne bacteria could result in the downwind dissemination to later plantings. A standard copper + mancozeb mixture applied on a weekly basis failed to control bacterial spot caused by *Xanthomonas campestris* pv. *vesicatoria*, or affect numbers of aerosolized bacteria above treated areas. Copper + mancozeb sprays prevented the apparent establishment of epiphytic populations of *Pseudomonas syringae* pv. *syringae*, but did not affect numbers of total aerosolized bacteria.

Additional keywords: bacterial speck, *Capsicum annuum*, *Lycopersicon esculentum*, *Pseudomonas syringae* pv. *tomato*

Southern Georgia is a major production area for pepper (*Capsicum annuum* L.) and tomato (*Lycopersicon esculentum* Mill.) transplants that are marketed in the northern United States and Canada (9,17). Bacterial spot of pepper and tomato, caused by *Xanthomonas campestris* pv. *vesicatoria* (Doidge) Dye, and bacterial speck of tomato, caused by *Pseudomonas syringae* pv. *tomato* (Okabe) Young, Dye, and Wilkie, can reduce yield and quality in both transplant and production fields (9,29). Infected transplants may serve as the source of initial inoculum for northern areas, consequently they are inspected rigorously. Confirmation of the presence of bacterial spot or bacterial speck in a transplant field results in rejection of certification by the Georgia Department of Agriculture (15). Syringae leaf spot of pepper and tomato, caused by *P. s.* pv. *syringae* van Hall, is relatively innocuous and is of concern only because of the difficulty in distinguishing its symptoms from the other bacterial diseases (9,17).

Some phytopathogenic bacteria can survive epiphytically on leaf surfaces for extended periods and cause disease when conditions are conducive (23,24). Specifically, *X. c.* pv. *vesicatoria* (22) and *P. s.* pv. *tomato* (28,31–33) survive as an epiphyte on tomato, and *P. s.* pv. *syringae* (6,11,12,25) survives epiphytically on several different host plants. In the absence of disease symptoms, epiphytic populations of *P. s.* pv. *tomato* may escape detection during the inspection of transplants (3). Within transplant fields, individual plants with epiphytic populations of phytopathogenic bacteria could serve as a source of inoculum for the entire planting. Plant canopies harboring epiphytic bacteria may also serve as major sources of aerosolized bacteria (25,26). Except for the role of aerosols in the dissemination of *Erwinia* spp. (10,30) and *P. s.* pv. *glycinea* (Coerper) Young et al (35), there are few reports on aerosol dispersal of phytopathogenic bacteria. Other than the report (21) of *X. c.* pv. *campestris* (Pammel) Dowson in California, nothing has been reported on the potential spread of *Xanthomonas* spp. in aerosols. Most studies have dealt with aerosolized bacteria that were generated through natural processes, and little attention has been given to bacteria-containing aerosols generated through cultural activities.

The present work was conducted to determine 1) the occurrence of bacteria-containing aerosols above tomato transplant fields in southern Georgia; 2) the effects of irrigation, clipping, and harvesting on the generation of bacterial aerosols; and 3) the effect of a weekly application of a copper + mancozeb mixture on the presence of aerosols containing phytopathogenic bacteria.

MATERIALS AND METHODS

Samples in commercial tomato and pepper transplant fields. Four commercial transplant fields were selected to sample for airborne bacteria in 1984. Fields one, two, and three in Berrien county, GA had a history of plants with syringae leaf spot. Field four, in Tift county, GA, was added later in the season after syringae leaf spot was detected by plant inspectors. Recommended seedbed preparation, planting, fertilization, irrigation, and pest control practices were used by the growers at all sites (9,13,14). Fields one, two, and three were planted with the tomato cultivars Campbell 4135, FM 6203, and Campbell 797, respectively. Field four was planted with the pepper cultivars Red Giant and Emerald Giant. Samples were taken from March through May, encompassing most of the tomato and pepper transplant season.

Air samples were collected with an Andersen six-stage viable microbial impaction sampler (Andersen Samplers Inc., Atlanta, GA 30336) (1) three times daily (0700–0900, 1130–1330, and 1530–1730 hours) and three times weekly from planting until harvest (40–45 days) at the three tomato fields. A petri plate with 27 ml of a selected agar medium (described below) was placed below each stage of the sampler that served as the sample area for particle impaction. The air sampler was placed with the inlet opening at plant canopy height (25 cm) within the plant bed, and a sample of air was drawn by a vacuum pump for 10 min

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at the rate of 28.3 L/min. Samples were collected at three subsites in each field. Air samples also were collected before and after clipping and harvesting at each subsite of all four fields.

Various agar media were used to facilitate the detection of the pathogenic bacteria of interest. King's medium B (KMB) (18) supplemented with cycloheximide (100 μg/ml) was used for *P. s.* pv. *syringae* or *P. s.* pv. *tomato*. A medium based on the use of DL-lactate (9) was also used for *P. s.* pv. *syringae*. Nutrient agar supplemented with cycloheximide (100 μg/ml) was used to sample for airborne *X. c.* pv. *vesicatoria*. After plates were incubated at 30 C for 72 hr, bacterial colonies were counted and categorized as saprophyte or suspected pathogen. The main criteria for this initial separation were colony color, morphology, and the production of a water-soluble, fluorescent pigment on KMB or DL-lactate when viewed under ultraviolet light. Further identification of fluorescent bacteria was made by determining oxidase reaction (20); arginine dihydrolase activity (34); use of and fluorescence on erythritol, D-tartrate, and DL-lactate (16); ice nucleation activity (15); and tobacco hypersensitivity (19). Yellow colonies suspected of being *X. c.* pv. *vesicatoria* were characterized by Gram reaction (8), gelatin hydrolysis (8), fermentative-oxidative acid production in glucose (8), and cellulolytic activity on a carboxymethylcellulose (CMC) medium (9). Tomato cultivar FM 6203 was used for pathogenicity tests (9).

Populations of *P. s.* pv. *syringae*, *P. s.* pv. *tomato*, or *X. c.* pv. *vesicatoria* on symptomless leaves of wild cherry (*Prunus serotina*) along field edges and tomato and pepper transplants were detected by washing bulk samples of 5 g of tissue (30–40 leaflets) in 50 ml of phosphate-buffered saline in an Erlenmeyer flask. Flasks were shaken on a rotary shaker at 200 rpm for 1 hr and a tenfold serial dilution was plated, 0.1 ml per plate, onto the media described above. Plates were incubated 3 days at 30 C and suspect colonies were characterized as above to confirm their identity. Strains identified as *P. s.* pv. *syringae*, *P. s.* pv. *tomato*, or *X. c.* pv. *vesicatoria* were tested for resistance to copper bactericides by the method of Marco and Stall (27).

Sampling in experimental field plots. Because syringae leaf spot was the only disease detected in commercial plantings in 1984, field plots inoculated with *P. s.* pv. *tomato* and *X. c.* pv. *vesicatoria* were established in 1985 on the Coastal Plain Experiment Station at Tifton at two sites separated by 4 km. Both sites were seeded with FM 6203 tomato at the rate of 100 seed per meter with rows 30 cm apart. The site inoculated with *X. c.* pv. *vesicatoria*, seeded 19 March, consisted of eight 16 × 16 m blocks, and a sampling subsite was established in the center of each block. The *P. s.* pv. *tomato* site, seeded 18 April, had 2 × 9 m beds. Recommended cultural and pest control practices (13,14) were used at both sites to simulate commercial transplant production. Strains *X. c.* pv. *vesicatoria* 83-38 and *P. s.* pv. *tomato* 83-36 were originally isolated from a commercial tomato planting in 1983. Both strains were tested for pathogenicity on greenhouse-grown tomato plants before their use in the field. Plants were inoculated with *X. c.* pv. *vesicatoria* (18 April) or *P. s.* pv. *tomato* (1 May) in the early evening hours after irrigation. Suspensions containing approximately 1 × 10^8 colony-forming units (cfu) of bacteria per ml of 0.01 M phosphate-buffered (pH 7.2) 0.85% saline were applied to runoff with a hand-operated pressurized sprayer (Acme Burgess, Inc., Grayslake, IL 60030) to plants in a 6-m diameter circle in the center of each block of the *X. c.* pv. *vesicatoria* site and to the entire bed of the *P. s.* pv. *tomato* site. Two chemical treatments were applied at each site at the sign of first true leaves. Half of the plots at each site were sprayed with cupric hydroxide (Kocide 101, 2.25 kg/ha) plus mancozeb (Manzate 200, 2.25 kg/ha) and half were sprayed with chlorothalonil (Bravo 500, 2.63 L/ha), a fungicide with no known bactericidal or bacteriostatic activity. The chemicals were applied at 7-day intervals with a standard boom sprayer with fan nozzles at a delivery pressure of 275.8 kPa.

Air samples were collected in each block at the *X. c.* pv. *vesicatoria* site with an Andersen air sampler, as described previously, before and after irrigation, clipping, and harvesting. Samples were taken on 27 April and 6, 13, 15, and 18 May before irrigation and after 2–4 cm of water was applied during a 1- to 1.5-hr period with solid-set overhead sprinklers. Air samples were collected before and after clipping on 26 April and 1, 8, 10, 15, and 19 May. All clippings were made with a power-take-off driven rotary mower. The first clipping was made at a plant height of 15 cm, which removed 5–8 cm of growth; all other clippings were made at 20–25 cm. Samples were collected before and after harvest on 21 May. Ten thousand plants at each subsite were harvested by hand, shaken to dislodge soil clinging to the roots, and packed 1,000 plants per wooden crate. All of the above operations were conducted to simulate commercial operations. Using the same procedures, air samples were collected at the *P. s.* pv. *tomato* site before and after irrigation and clipping on 22, 26, and 29 May and before and after harvest on 1 June. Nutrient agar supplemented with 100 μg/ml of streptomycin sulfate and 0.5 ml/L of chlorothalonil and KMB were used in the sampler as the collection media in the *X. c.* pv. *vesicatoria* plots. King's medium B supplemented with 100 μg of cycloheximide per milliliter was

Table 1. Number of total bacteria (cfu) recoverd in aerosol particles during three sampling periods in commercial tomato transplant fields in southern Georgia during 1984

Sampling time[x]	Mean $\log_{10}$ cfu/m^3 of air[y]
0700–0900	0.89 a[z]
1130–1330	1.02 b
1530–1730	1.12 c

[x] Summary of data from three fields with three replications per field. Sampling periods were for 10 min for each replication. Samples were taken with an Andersen viable impaction sampler.

[y] Total count of all bacteria as aerosols (486 observations per sampling time).

[z] Means followed by different letters are significantly different ($P = 0.05$).

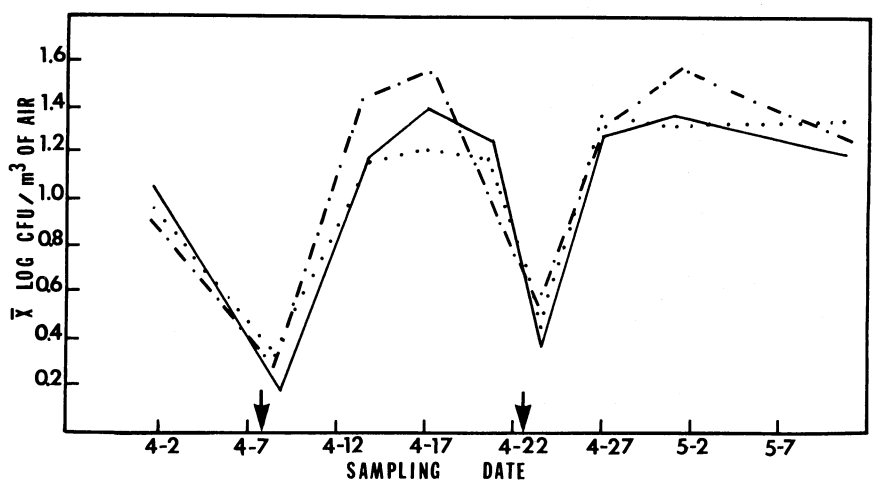

Fig. 1. Occurrence of airborne bacteria in three commercial tomato transplant fields in southern Georgia during April and May of 1984. Arrows denote 1.9 cm and 13.8 cm of rain on 8 April and 22 April, respectively.

used in the *P. s.* pv. *tomato* plots. Plates were removed from the sampler, incubated 3–5 days at 30 C, and counts of total bacteria and suspected pathogens were made as described previously. Colonies suspected of being *X. c.* pv. *vesicatoria* or *P. s.* pv. *tomato* were picked, characterized as described previously, and tested for pathogenicity.

Plots at both sites were rated for disease severity on a scale from 1 = healthy, 2 = trace, 3 = mild infection, to 10 = severe defoliation. Bacterial spot ratings were made on whole plots and bacterial speck ratings were based on a sample of 100 plants per plot. Leaf washings were made as described above for the detection of resident populations.

RESULTS

Aerosolized bacteria in commercial transplant fields. Airborne bacteria were recovered during all three daytime sampling periods. However, significantly more bacteria were recovered during 1530–1730 hours than at other time periods (Table 1). Numbers of airborne bacteria also were related to rainfall. Rain occurred only two times during the course of the experiment, 1.9 cm on 8 April and 13.8 cm on 22 April. Both rains resulted in marked reductions in airborne bacteria that were recovered (Fig. 1). Large particles, greater than 7.0 μm in diameter, were the predominate particle size sampled at all three locations during all sampling time periods (Fig. 2).

Although syringae leaf spot had been observed in the tomato fields each of the previous 3 years, the disease did not occur in 1984. Moreover, *P. s.* pv. *syringae* was not detected among bacteria in the aerosols sampled from those locations. However, both clipping and harvesting increased recovery of the numbers of total bacteria including fluorescent, saprophytic pseudomonads. Fungi and nontarget bacteria were a problem in detecting the target organisms (*P. s.* pv. *syringae*, *P. s.* pv. *tomato*, and *X. c.* pv. *vesicatoria*) that grew on KMB or nutrient agar. However, the DL-lactate medium suppressed nontarget organisms adequately so that *P. s.* pv. *syringae* could be detected. Epiphytic populations of *P. s.* pv. *syringae* were detected from March through May on wild cherry leaves on the trees as well as on leaves on the ground beneath transplant canopies at fields one, two, and four. Despite the presence of these epiphytic populations, *P. s.* pv. *syringae* occurred in an aerosolized state only at field four where diseased transplants were present, and then only after the clipping of plants.

Aerosolized bacteria in field plots inoculated with *X. c.* pv. *vesicatoria*. Populations of *X. c.* pv. *vesicatoria* were recovered from leaf washes throughout the test period. A cupric hydroxide + mancozeb mixture had no significant effect on the recovery of *X. c.* pv. *vesicatoria* from leaf washes during the course of the experiment, as the mean population of *X. c.* pv. *vesicatoria* was 5 $\times 10^5$ cfu/g of tissue for both treated and control plants. In laboratory tests, *X. c.* pv. *vesicatoria* 83-38 was tolerant to the recommended field rate of cupric hydroxide but sensitive to a copper + mancozeb mixture. However, the copper + mancozeb treatment had no effect on the total number of airborne bacteria nor did it control disease, as the disease levels in control plots (8.5) were not significantly different ($P = 0.05$) from disease levels in treated plots (7.1). Only 23 percent of yellow rod-shaped bacteria that were on the medium supplemented with streptomycin were confirmed as *X. c.* pv. *vesicatoria* by being proteolytic, cellulolytic on CMC, gram-negative, aerobic, and pathogenic on tomato. The greatest number of bacteria, including *X. c.* pv. *vesicatoria*, were recovered on stage one of the air sampler.

The numbers of aerosolized bacteria recovered after clipping were significantly greater than the numbers of bacteria recovered before clipping (Table 2). The number of aerosol particles containing *X. c.* pv. *vesicatoria* generated during clipping was negatively correlated with time both in control plots and in plots treated with copper + mancozeb (Fig. 3).

Harvesting also increased the number of aerosolized bacteria. However, at harvest the populations of airborne *X. c.* pv. *vesicatoria* had declined to the point that *X. c.* pv. *vesicatoria* was not detected as an aerosol either before or after harvest (Table 2). Irrigation reduced the number of airborne bacteria (Table 2). However, this phenomenon was of much shorter duration than the reductions caused by rain in 1984. By the next day, the reductions caused by irrigation were not apparent.

Aerosolized bacteria in field plots inoculated with *P. s.* pv. *tomato*. Despite the inoculation of tomato with *P. s.* pv. *tomato* and the occurrence of bacterial speck in the field plots, *P. s.* pv. *tomato* was not recovered from tomato leaflets when standard leaf-washing procedures for the detection of epiphytes were used. Although plants were not inoculated with *P. s.* pv. *syringae*, it was recovered from tomato leaflets of plants in control plots but not from leaflets of plants treated with copper + mancozeb.

As in all previous cases, the greatest numbers of bacteria recovered during air sampling were from particles exceeding 7.0 μm in diameter collected on plates in stage one of the air sampler. Significantly more airborne bacteria, including fluorescent pseudomonads, were recovered after harvest compared with before harvest sampling periods. As in previous clipping experiments, there was a negative correlation between the number of airborne bacteria detected and the date of clipping (Fig. 4). This phenomenon occurred in plots treated with copper + mancozeb as well as in nontreated control plots. In general, there were

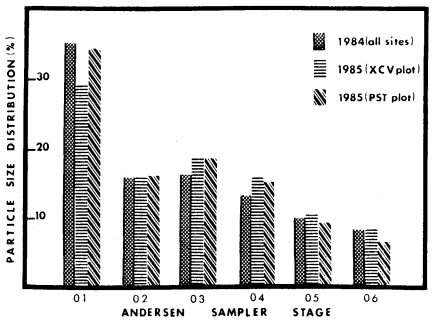

Fig. 2. Percent distribution of airborne bacteria by particle size recovered above three commericial tomato transplant fields in 1984 and *Xanthomonas campestris* pv. *vesicatoria* and *Pseudomonas syringae* pv. *tomato* field plots in 1985.

Table 2. Effect of selected cultural practices on the number of airborne bacteria recovered in 1985 above tomato transplants that had been inoculated with *Xanthomonas campestris* pv. *vesicatoria* (XCV)

Cultural practice and sampling time	Mean $\log_{10}$ cfu total bacteria/m^3 of air	Mean $\log_{10}$ cfu XCV/m^3 of air[x]
Clipping		
Before	0.65 a[y]	0.03 a
After	0.96 b	0.05 b
Irrigation		
Before	0.33 a	0.01 a
After	0.16 b	0.01 a
Harvest		
Before	0.03 a	0.00
After	0.78 b	0.00
Bactericide application[z]		
Before	0.68 a	0.03 a
After	0.65 a	0.02 a

[x] Data are a summary of sampling times with four replications per treatment.
[y] Paired means with the same letter are not significantly different ($P = 0.05$).
[z] Control plots were sprayed with chlorothalonil (2.63 L/ha) and treated plots with cupric hydroxide (2.25 kg/ha) plus mancozeb (2.25 kg/ha).

greater numbers of fluorescent bacteria recovered in the *P. s.* pv. *tomato* plot than in the *X. c.* pv. *vesicatoria* plot. In the *P. s.* pv. *tomato* plot, 3.1% of the bacteria recovered were *P. s.* pv. *tomato*, 1.6% were *P. s.* pv. *syringae*, and the remaining 95.3% were in the *P. fluorescens* group. Fluorescent pseudomonads isolated from bacterial specklike symptoms were identified as *P. s.* pv. *tomato* by their negative reactions for oxidase, arginine dihydrolase, ice nucleation activity, inability to use DL-lactate and erythritol, and a positive response for a hypersensitive reaction in tobacco. *Pseudomonas syringae* pv. *syringae* isolates recovered from leaf washes or in aerosol particles were negative for oxidase and arginine dihydrolase, were ice nucleation active, and readily used DL-lactate and erythritol. Chemical-treated and control plots had mean disease severity ratings of 1.1 and 2.7, respectively, which were significantly different at $P = 0.05$.

DISCUSSION

Although bacteria-containing aerosols have been implicated in the dissemination of phytopathogenic bacteria elsewhere (10,21,30,35), we could find no previous reports concerning the role of bacterial aerosols under conditions in the southeastern United States. In our study, the tomato pathogens *X. c.* pv. *vesicatoria*, *P. s.* pv. *syringae*, and *P. s.* pv. *tomato* were detected in air samples taken at one time or another under typical conditions that occur during the spring transplant season in southern Georgia. Some useful information was obtained in 1984 from total bacterial air flora. However, there were some major disadvantages in working in commercial fields. The sample sites in 1984 were selected based on the occurrence of syringae leaf spot in past seasons. Unlike bacterial speck or bacterial spot that occur sporadically and unpredictably, syringae leaf spot has occurred on a regular basis in certain transplant fields. Because of past problems with syringae leaf spot, the growers routinely applied bactericides and fungicides to plant foliage. These measures could affect populations of epiphytic bacteria that are likely sources of aerosolized bacteria (25). *Pseudomonas syringae* pv. *syringae* was detected above commercial fields only once in 1984, after clipping of infected pepper transplants. Lack of recovery before clipping might be attributed to suppression of epiphytic populations by foliar bactericides. However, clipping could generate *P. s.* pv. *syringae*-containing aerosols by the violent release of bacteria from diseased tissues. We observed that *P. s.* pv. *syringae* populations were recovered from bulk washes of nontreated leaves but were not recovered from leaves treated with copper + mancozeb in field plots in 1985. Sensitivity to bactericides could explain why *P. s.* pv. *syringae* was not detected in nonclipped plants in 1984 when all were treated with bactericides. Although the *X. c.* pv. *vesicatoria* strain in our study was sensitive to copper + mancozeb, the bactericides had no apparent effect on the recovery of *X. c.* pv. *vesicatoria* from leaf washes in 1985. Either epiphytic populations of *X. c.* pv. *vesicatoria* were not affected by the bactericides, or bacteria were washed from latent infections from symptomless leaves during the leaf washing process. In addition, the bactericides had no apparent effect on disease control or on the recovery of *X. c.* pv. *vesicatoria* in aerosols above treated tomato plants. More work with *P. s.* pv. *syringae*, *P. s.* pv. *tomato*, and *X. c.* pv. *vesicatoria* is needed to clarify the effect of bactericides on epiphytic populations and airborne bacteria.

Possible bactericidal effects do not explain why *P. s.* pv. *syringae* was not readily recovered in air samples taken adjacent to nonsprayed wild cherry trees that harbored leaf surface-residing populations of *P. s.* pv. *syringae*. In Wisconsin, *P. s.* pv. *syringae* was recovered in air samples in bean fields under dry conditions when there was an upward flux of bacteria (26). Air samples were collected in tomato transplant fields under similar conditions when radiant energy was the probable means of aerosol generation (4). Wild cherry leaves, even

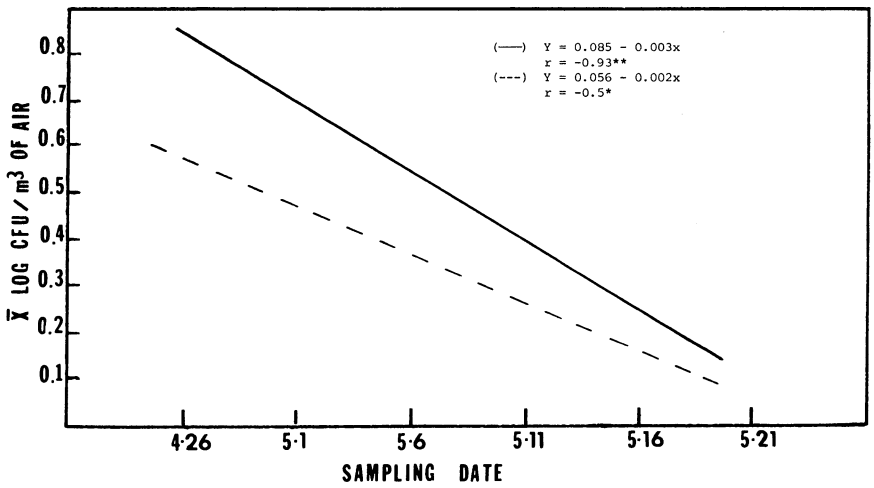

Fig. 3. Occurrence of airborne colony-forming units of *Xanthomonas campestris* pv. *vesicatoria* after clipping of tomato transplants in field plots in southern Georgia during April and May 1985. The solid line represents numbers of airborne *X. c.* pv. *vesicatoria* recovered above nontreated control plots and the dashed line represents airborne *X. c.* pv. *vesicatoria* detected above plots treated with copper + mancozeb. Correlation coefficients are significantly greater than zero at * = 0.05 and ** = 0.01 probability levels.

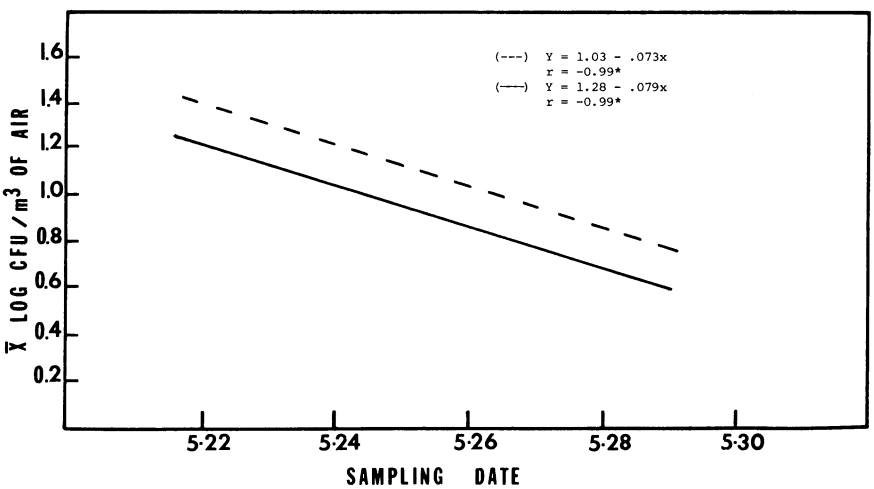

Fig. 4. Occurrence of airborne colony-forming units of *Pseudomonas syringae* pv. *tomato* after clipping tomato transplants in field plots in southern Georgia during April and May 1985. The solid line represents numbers of airborne *P. s.* pv. *tomato* recovered above nontreated control plots and the dashed line represents airborne *P. s.* pv. *tomato* detected above plots treated with copper + mancozeb. Correlation coefficients are significantly greater than zero at * = 0.05 and ** = 0.01 probability levels.

on the smallest trees, were well above the canopy level of transplant beds where the air sampler inlet was positioned. Thus, if *P. s.* pv. *syringae* cells moved in an upward flux, they might have been above the air layer that was being sampled. However, this does not preclude *P. s.* pv. *syringae*-containing aerosols as a potential source of inoculum in tomato or pepper fields. Under certain conditions, a net downward flux can occur (26) or bacteria can be washed out of the air during rain or irrigation.

Our data agree with earlier findings (26) that highest populations of aerosolized bacteria occur during warm, sunny periods (1530–1730 hours in our study). Apparently, bacteria on plants became airborne by means of upward movements generated by radiant energy (4). In both 1984 and 1985, the predominant particle size recovered was greater than 7.0 μm in diameter and impacted on stage one of the air sampler. Previous reports indicated that particles 2.1–3.3 μm in diameter were the most common size recovered (21,35). The reason for this difference is not known because the data base was too small to speculate whether environment, different crops under study, different cultural practices, or other causes were responsible. Particle size could be important in the dissemination and survival of airborne bacteria. Small particles are disseminated greater distances than large particles (2,7), but bacterial survival could be greater in large particles (4). Large particles also may contain more than one bacterium and may support one or more cell divisions (5). Chances of cell survival and establishment of an epiphytic population seem more likely if large particles with multiple cells impact on leaf surfaces as opposed to single cell aerosol particles, although little data are available to support this contention.

Previous reports (21,35) have documented an increase in the number of airborne bacteria during rain or irrigation, and we observed a decline in airborne bacteria after rain and irrigation due to a "washing out" effect. Lindemann and Upper (26) observed a strong net downward flux of bacteria during rain and a substantial removal of bacteria as they were washed off of leaves onto soil. Such a phenomenon could account for the decline of bacterial numbers in our observations.

As expected, cultural practices such as clipping and harvesting generated higher numbers of airborne bacteria that could be disseminated to other plantings immediately adjacent to or within a reasonable distance from the site of activity. However, it was unexpected, and is not known, why the generation of bacterial aerosols by clipping decreased as the season progressed. Time of the season does not seem to be the only factor involved because similar results were obtained in two tests that had overlapping dates. "Hardening" of plants as they are progressively clipped and decreased intervals between clippings that result in removal of less plant material may be partially responsible. If these results accurately reflect typical field conditions, it could mean reduced chances of bacterial dissemination through aerosols later in the season when plants are extensively clipped. However, harvesting may generate bacterial aerosols that disseminate plant pathogenic bacteria to nearby nonharvested fields. Possible control strategies might include a spray program of bactericides to reduce populations of epiphytic bacteria coordinated with irrigation immediately following clipping or harvest to induce a net downward flux of bacteria to prevent long-distance dissemination to other plantings.

LITERATURE CITED

1. Andersen, A. A. 1958. New sampler for the collection, sizing and enumeration of viable airborne particles. J. Bacteriol. 76:471 484.
2. Bausum, H. T., Schaub, S. A., Kenyon, K. F., and Mitchell, J. 1982. Comparison of coliphage and bacterial aerosols at a wastewater spray irrigation site. Appl. Environ. Microbiol. 43:28-38.
3. Bonn, W. G., Gitaitis, R. D., and MacNeill, B. H. 1985. Epiphytic survival of *Pseudomonas syringae* pv. *tomato* on tomato transplants shipped from Georgia. Plant Dis. 69:58-60.
4. Dimmick, R. L., and Akers, A. B., eds. 1969. An Introduction to Experimental Aerobiology. Wiley-Interscience, New York. 494 pp.
5. Dimmick, R. L., Wolochow, H., and Chatigny, M. A. 1979. Evidence for more than one division of bacteria within airborne particles. Appl. Environ. Microbiol. 38:642-643.
6. Ercolani, G. L., Hagedorn, D. J., Kelman, A., and Rand, R. E. 1974. Epiphytic survival of *Pseudomonas syringae* on hairy vetch in relation to epidemiology of bacterial brown spot of bean in Wisconsin. Phytopathology 64:1330-1339.
7. Fannin, K. F., Vana, S. C., and Jakabowski, W. 1985. Effect of an activated sludge wastewater treatment plant on ambient air densities of aerosols containing bacteria and viruses. Appl. Environ. Microbiol. 49:1191-1196.
8. Gerhardt, P., Murray, R. G. E., Costilow, R. N., Nester, E. W., Wood, W. A., Krieg, N. R., and Phillips, G. B., eds. 1981. Manual of Methods for General Bacteriology. American Society for Microbiology, Washington, DC. 542 pp.
9. Gitaitis, R. D., Jones, J. B., Jaworski, C. A., and Phatak, S. C. 1985. Incidence and development of *Pseudomonas syringae* pv. *syringae* on tomato transplants in Georgia. Plant Dis. 69:32-35.
10. Graham, D. C., and Harrison, M. D. 1975. Potential spread of *Erwinia* spp. in aerosols. Phytopathology 65:739-741.
11. Gross, D. C., Cody, Y. S., Proebsting, E. L., Jr., Radamaker, G. K., and Spotts, R. A. 1983. Distribution, population dynamics, and characteristics of ice nucleation-active bacteria in deciduous fruit tree orchards. Appl. Environ. Microbiol. 46:1370-1379.
12. Hirano, S. S., Nordheim, E. V., Arny, D. C., and Upper, C. D. 1982. Lognormal distribution of epiphytic bacterial populations on leaf surfaces. Appl. Environ. Microbiol. 44:695-700.
13. Jaworski, C. A., Brodie, B. B., Glaze, N. C., McCarter, S. M., Goode, J. M., and Webb, R. E. 1973. Research studies on field production of tomato transplants in southern Georgia. U.S. Dep. Agric. Prod. Res. Rep. 148. 58 pp.
14. Jaworski, C. A., and Webb, R. E. 1966. Influence of nutrition, clipping and storage of tomato transplants on survival and yield. Proc. Fla. State Hortic. Soc. 79:216-221.
15. Jones, J. B., Gitaitis, R. D., and McCarter, S. M. 1983. Evaluation of indirect immunofluorescence and ice nucleation activity as rapid tests for identifying foliar diseases of tomato transplants incited by fluorescent pseudomonads. Plant Dis. 67:684-687.
16. Jones, J. B., Gitaitis, R. D., and McCarter, S. M. 1984. Fluorescence of individual carbon sources for identification of fluorescent phytopathogenic pseudomonads in leaf spots of tomato. Pages 39-42 in: Proceedings of the 2nd Working Group on *Pseudomonas syringae* Pathovars. Sounion, Greece.
17. Jones, J. B., McCarter, S. M., and Gitaitis, R. D. 1981. Association of *Pseudomonas syringae* pv. *syringae* with a leaf spot disease of tomato transplants in southern Georgia. Phytopathology 71:1281-1285.
18. King, E. O., Ward, M. K., and Raney, D. E. 1954. Two simple media for the demonstration of pyocyanin and fluorescin. J. Clin. Med. 44:301-307.
19. Klement, Z., Farkas, G. L., and Lovrekovich, L. 1964. Hypersensitive reaction induced by phytopathogenic bacteria in the tobacco leaf. Phytopathology 54:474-477.
20. Kovacs, N. 1956. Identification of *Pseudomonas pyocyanea* by the oxidase reaction. Nature 178:703.
21. Kuan, T.-L., Minsavage, G. V., and Schaad, N. W. 1986. Aerial dispersal of *Xanthomonas campestris* pv. *campestris* from naturally infected *Brassica campestris*. Plant Dis. 70:409-413.
22. Leben, C. 1963. Multiplication of *Xanthomonas vesicatoria* on tomato seedlings. Phytopathology 53:778-781.
23. Leben, C. 1965. Epiphytic microorganisms in relation to plant disease. Annu. Rev. Phytopathol. 3:209-230.
24. Leben, C. 1981. How plant-pathogenic bacteria survive. Plant Dis. 65:633-637.
25. Lindemann, J., Constantinidou, H. A., Barchet, W. R., and Upper, C. D. 1982. Plants as sources of airborne bacteria, including ice nucleation-active bacteria. Appl. Environ. Microbiol. 44:1059-1063.
26. Lindemann, J., and Upper, C. D. 1985. Aerial dispersal of epiphytic bacteria over bean plants. Appl. Environ. Microbiol. 50:1229-1232.
27. Marco, G. M., and Stall, R. E. 1983. Control of bacterial spot of pepper initiated by strains of *Xanthomonas campestris* pv. *vesicatoria* that differ in sensitivity to copper. Plant Dis. 67:779-781.
28. McCarter, S. M., Jones, J. B., Gitaitis, R. D., and Smitley, D. R. 1983. Survival of *Pseudomonas syringae* pv. *tomato* in association with tomato seed, soil, host tissue, and epiphytic weed hosts in Georgia. Phytopathology 73:1393-1398.
29. McCarter, S. M., and Ratcliffe, T. J. 1977. Incidence of major diseases on tomato transplants produced in Georgia. Plant Dis. Rep. 61:129-131.
30. Perombelon, M. C. M., Fox, R. A., and Lowe, R. 1978. Dispersion of *Erwinia carotovora* in aerosols produced by the pulverization of potato haulm prior to harvest. Phytopathol. Z. 94:249-260.
31. Schneider, R. W., and Grogan, R. G. 1977. Bacterial speck of tomato: Sources of inoculum and establishment of a resident population. Phytopathology 67:388-394.
32. Schneider, R. W., and Grogan, R. G. 1977. Tomato leaf trichomes, a habitat for resident populations of *Pseudomonas tomato*. Phytopathology 67:898-902.
33. Smitley, D. R., and McCarter, S. M. 1982. Spread of *Pseudomonas syringae* pv. *tomato* and role of epiphytic populations and environmental conditions in disease development. Plant Dis. 66:713-717.
34. Thornley, M. J. 1960. The differentiation of *Pseudomonas* from other gram-negative bacteria on the basis of arginine metabolism. J. Appl. Bacteriol. 23:37-52.
35. Venette, J. R., and Kennedy, B. W. 1975. Naturally produced aerosols of *Pseudomonas glycinea*. Phytopathology 65:737-738.